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THE INTERCEPTION OF FOG AND CLOUD WATER ON WINDWARD MAUNA LOA, HAWAII[1]

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ABSTRACT

Fog drip is an important parameter in the water balance of montane forest ecosystems on Mauna Loa (summit elevation 4170 m). In the present study relative fog interception was sampled on the windward slope of Mauna Loa, along an altitudinal transect from 600 to 3400 m. Stations were instrumented with louvered aluminum screen fog interceptors, paired to standard rain gages. The analysis of weekly rain and fog data over an 11 month period exposed the substantial contribution of fog in the mid-mountain belt between 1500 and 2500 m, particularly during the summer months with low direct rainfall. A set of simple regression equations were derived to predict fog interception as a function of rainfall and elevation.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The direct interception of fog and cloud water by vegetation has been demonstrated in many parts of the world, and may play a particularly important role in areas where onshore maritime air is modified by orographic influence (Nagle 1956, South Africa; Oberlander 1956, California; Espinoza and Munoz 1967, Chile; and Vogelmann 1973, Eastern Mexico).

Mauna Loa, an active shield volcano (summit elevation 4170 m) on the Island of Hawaii presents an imposing barrier to the path of prevailing northeast tradewind flow. Orographic rainfall is copious on the lower slopes, with the belt of maximum annual rainfall (exceeding 5,000 mm) lying between 600 and 900 m, corresponding to the average elevation of the dewpoint temperature. The prevailing tradewind circulation is characterized by a temperature inversion with a modal elevation of 1800 m. The overlying dry and stable air limits deep vertical development of orographic and convective clouds. Annual precipitation (rain + snow) in the summit area of Mauna Loa averages less than 600 mm. Fog occurs frequently on the higher slopes of Mauna Loa, and fog drip has been qualitatively assessed as an important source of moisture for montane forest communities. Mueller-Dombois (1967) commented on the increased density and vigor of herbaceous plant communities under isolated trees near timber line on Mauna Loa and Mauna Kea, as compared with those in adjacent open areas, and attributed the difference to the fog drip effect under trees. This phenomenon has also been described by Vogelmann (1973:99) in mountain areas of Eastern Mexico.

Ekern (1964) conducted an extensive series of experiments dealing with fog interception on Lanaihale, Lanai (elevation 840 m) in the Hawaiian Islands. He found that water collected under a Norfolk Island Pine tree (*Araucaria excelsa*) during the low rainfall summer months equaled about 13 fold the rainfall in adjacent open areas. Ekern also experimented with mechanical fog interceptors, employing a variety of plastic, metal and fiberglass screens and filters. Those materials with the highest interception efficiencies collected about 40% of the direct rainfall (per unit vertical area) on an annual basis, and up to 300% during low rainfall summer months.

Studies of orographic cloud structure on the slopes of Mauna Loa by Squires and Warner (1957) suggest at least a partial explanation for the frequent fog conditions in the mountain areas of Hawaii. The average depth of orographic clouds decrease from about 1200 m at sea level to a depth of 600 m at inland elevations of 1800 m. There is a fairly sharp transformation from cumuliform structure near the coast to stratiform on the upper slopes. The general structure and shallow cloud depth at higher inland elevations would necessarily limit the growth of water droplets. The cloud droplet spectra obtained for low lying orographic clouds by Squires and Warner (1957:480) show an abundance of droplets in the 12-18 micron range which Grunow (1960:115) considered optimum for interception by wire screens and forest trees in the windward Alps.

This paper presents a quantitative description of the fog belt on windward Mauna Loa, and an analysis of the statistical relationship between fog, rainfall, and elevation. The study represents the first phase of a continuing research project on the contribution of intercepted fog and cloud moisture in the water balance of montane forest ecosystems, and the feasibility of developing large scale vertical catchment systems for domestic and agricultural water supply.

RESEARCH DESIGN

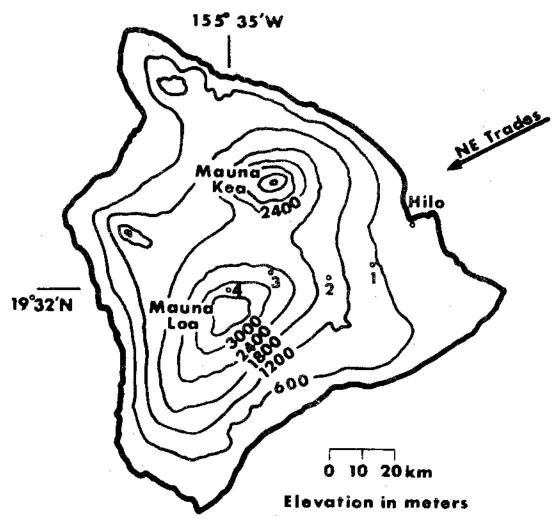
Four sampling sites for fog interception were selected on windward Mauna Loa at elevations of 610, 1580, 2530, and 3415 m, corresponding to the location of official U. S. Weather Bureau rain gage stations (see FIG. 1).

Fog interceptors were constructed of louvered aluminum shade screen, fashioned into cylinders 15.2 cm in diameter and 56.4 cm in height, with a surface area of 2691 cm^2 or 8.3 times the cross-sectional area of the standard 8 inch rain gages also employed in the study. Louvered shade screen, with the louvers aligned vertically to enhance drainage of intercepted water, was selected for gage construction over a number of alternative wire screen materials, primarily because the louvers were considered somewhat more analogous to tree leaves than wire mesh (and thus a better indication of the fog interception by adjacent mountain forest trees). In addition Ekern (1964:420) found the louvered screen one of the most efficient water collectors in comparative interception experiments at Lanaihale, Lanai.

The louvered screen cylinders were anchored in sheet metal funnels of a slightly large diameter (2 mm), and mounted on tripods with the screens centered at 3 m above the ground. The drainage funnel fed collected water via a flexible plastic tube into a covered 8 inch standard rain gage at ground level. At each sampling station the fog interceptors were placed in open, exposed sites, adjacent to existing U. S. Weather Bureau standard rain gages.

The fog interception cylinders were open at the top, and thus collected direct rainfall as well as horizontal fog. The contribution of fog was isolated by subtracting (after correcting for the difference in gage diameters) the amount of rain water collected in the adjacent rain gage from the combined rain and fog collected by the screen interceptor.

In order to examine the general comparability of direct rainfall measurements by the fog interceptor and the standard rain gage, and particularly the problem of non-vertical, wind-blown rain and its interaction with the vertical silhouette of the fog interceptor, short term experiments were conducted in a



HAWAII

FIG. 1. Location of fog sampling stations on windward Mauna Loa.

non-fog area at sea level (Hilo).

The fog interceptors collected direct rainfall with good "within-group" precision, and in the absence of fog measured direct rainfall with acceptable accuracy (averaging 5% over standard rain gage values), even during periods of substantial non-vertical rainfall. This suggested that the non-vertical rainfall component deflected into the interceptor after striking the windward side of the screen cylinder was not an important factor.

In the analysis of fog data collected during the study, after subtracting the rainfall component the fog values were reduced to "unit vertical catch," that is, the amount of water that would have been collected by a screen equal in area to the companion rain gage (for the louvered screen fog interceptors, a value 1/8.3 of the total fog collected).

Rain and fog gages were read at weekly intervals over an 11 month period extending from October 1972 to September 1973. Readings at station #1 (elevation 610 m) were discontinued in April 1973.

On the assumption that fluctuations in the trade wind inversion would influence the incidence of rain and fog at different elevations, the average weekly height and strength of the trade wind inversion were computed from twice daily radiosonde data taken at Hilo, Hawaii.

RESULTS AND DISCUSSION

FIG. 2, presents a graphic summary of the cumulative rainfall and fog at stations 1-4, for the 28 week period extending from October 1972 through April 1973. During the sampling period the measured rainfall at all stations was substantially below the long term averages, ranging from 53% of normal at station #4 to 78% at station #3. An examination of FIG. 2, illustrates the increase in

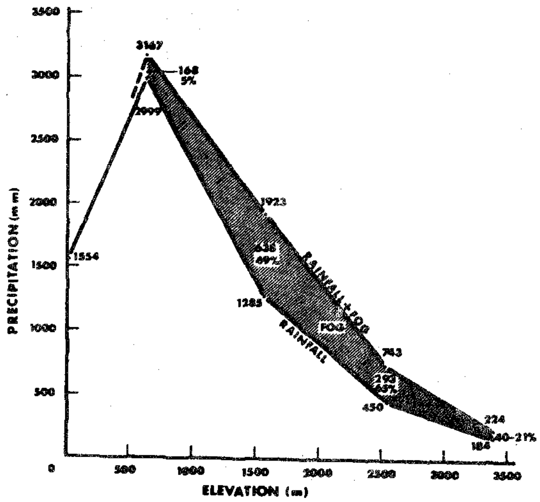


FIG. 2. Cumulative rainfall and fog interception, October 1972 to April 1973 (28 weeks). The contribution of fog is shaded, with absolute values in mm, and also expressed as a percentage of the total rainfall.

the relative contribution of fog with elevation, reaching a maximum at 2500 m where the fog intercepted per unit vertical area was 65% of the direct rainfall. Absolute fog interception was greatest at 1580 m yielding 638 mm over the 7 month period. At station #1, no surface level fog or cloud was observed during the study period and the difference between rain and fog gage values was not statistically significant. The magnitude of intercepted fog water during this period clearly indicates its importance in the water balance of mountain forest ecosystems on Mauna Loa, particularly at elevations, between 1500-2500 m, where fog interception becomes an increasingly larger fraction of the decreasing "total" precipitation.

Throughout the summer of 1973 a severe drought extended over much of the island of Hawaii, with county drought disaster declarations activated for several particularly hard hit areas. Over a 13 week period, June through August, the absolute values of both rainfall and fog interception were very low at all four sampling stations, however, relative to rainfall, the contribution of fog interception increased dramatically. Station three provides the best example of this shift; rainfall occurred during only 6 of the 13 weeks, with the total for the period equaling 64.5 mm, or 32% of normal. In contrast fog interception was recorded during 11 of the 13 weeks, yielding 87.1 mm (unit vertical catch), or 136% of the rainfall over the same period, this compared with the 65% figure for the winter months (FIG. 2). Summer fog interception likewise increased at station 2, to 66% of rainfall (from the winter value of 49%). At station 4 no rain or fog interception occurred during 9 of the 13 weeks, and for the remaining weeks with light rain, fog interception was negligible. The results from station 3, demonstrate the particular significance of fog during summer dry periods, in this belt, and conform to the observations of Ekern (1964) on Lanai, and Vogelmann

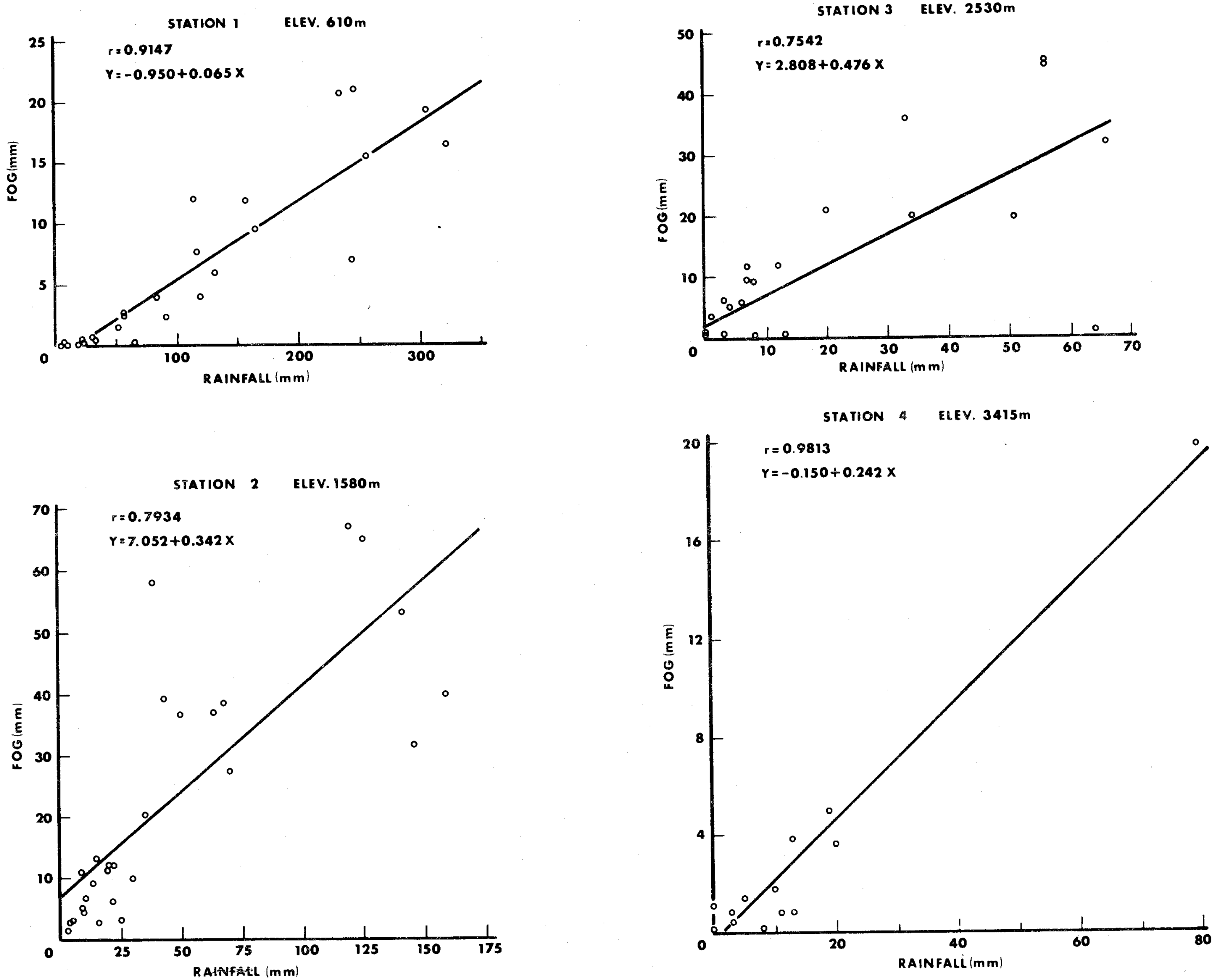
(1973) in the cloud forests of the Sierra Occidental in Eastern Mexico.

Data on weekly rainfall and fog interception for the winter period along with parameters on the trade wind inversion were subjected to simple linear regression, and stepwise multiple regression analysis. The assumption that weekly rainfall and fog interception should be highly correlated, insofar as both would result from the same general atmospheric conditions favoring condensation, was born out by the simple linear regression analysis of weekly rainfall and fog interception for data grouped by elevation. FIG. 3 illustrates the relationships between rainfall and fog interception at stations 1-4 (the regression equations are also presented). Correlation coefficient ranged from 0.75 to 0.98. Pooling the station data reduced the correlation coefficient to 0.42. In an effort to increase the explained variation in fog interception both pooled and stratified (by elevation) data were subjected to multiple regression analysis by the addition of the variables, inversion strength and height. Neither added significantly to the explained variation in fog interception. While inversion characteristics are generally related to precipitation development in the higher mountain areas of Hawaii, the failure to demonstrate a significant relationship in this study probably reflects the fact that inversion height and strength values were computed on a weekly basis by averaging twice daily data, showing wide variation. The resulting weekly averages for the inversion parameter probably bore little resemblance to the actual values for those limited periods during the week when precipitation occurred.

CONCLUSION

The present study has demonstrated the important contribution of fog interception in the mountain forest belt of Mauna Loa (1500-2500 m), particularly

FIG. 3. WEEKLY RAINFALL AND FOG INTERCEPTION ON MAUNA LOA (OCTOBER 1972 – APRIL 1973)



during dry summer periods. Research involving the sub-canopy catchment of fog drip under different forest types is now in progress to determine comparative interception efficiencies and establish empirical relationships between forest fog drip and water collected by the louvered aluminum screen interceptors. Rainfall and fog are strongly correlated, and simple regression equations have been derived to predict fog from rainfall and elevation data.

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